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14. ABSTRACT
We have studied the nonlinear microwave response of epitaxial HTS thin films in collaboration with Dr. Dan Oates at MIT Lincoln Lab. In order to make highest quality control. The nonlinearity of single layer YBCO degrades as the films are grown thicker due to the degradation of the crystalline quality and flux pinning of YBCO films. However, YBCO/CeO2 multilayer stacks shows significatn improvement of high-power capabilities.

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Final Report

Period: May 1, 2003 – April 30, 2006

Title: Microwave Properties of Atomic Layer Controlled HTS Thin Films
Contract number:

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Background:

One of the first areas of practical application for high temperature superconductor devices is passive microwave circuits. Future DOD systems such as AMRFS and CRYORADAR depend on extremely sharp filter and resonator functions. However, nonlinear effects and intermodulation distortion (IMD) can defeat the advantages gained by going to HTS components. In order to maximize device performance, much effort has been expended in learning how to fabricate HTS thin film materials with very low surface resistance. In addition to low microwave loss, however, HTS materials can exhibit detrimental nonlinear behavior at microwave frequencies. Since the origins of nonlinearity in HTS devices are not well understood, it is not immediately obvious if the same film growth conditions that lead to low surface resistance will also produce low nonlinearity.

Objectives:

- Exploring methods to lower nonlinear effects. Thicker films either grown by multilayer techniques or by a single deposition are expected to lower intermodulation distortion (IMD), based upon recent theoretical calculations.
- Measurements of intermodulation distortion (IMD) as a function of temperature and power of YBCO thin films by atomic-layer-controlled growth in order to understand the loss mechanisms and the nonlinear mechanisms.
- This study will point to the direction where we should go to improve the microwave properties and determine what kind of defects and disorder affect on the surface resistance and nonlinearity, in order to develop films and devices optimized for both low surface resistance and low nonlinearlity.

Activities

We have studied the nonlinear microwave response of epitaxial HTS thin films in collaboration with Dr. Dan Oates at MIT Lincoln Lab. In order to make highest quality control, $YBa_2Cu_3O_{7-d}$ epitaxial films were fabricated on single-surface-terminated (001) $LaAlO_3$ and (001) $(LaAlO_3)_{0.3}(Sr_2AlTaO_6)_{0.35}$ (LSAT) substrates by atomic layer controlled pulsed laser deposition. We explored the effects of various deposition parameters which include deposition temperatures, film thicknesses and substrate types and miscut angles. Films were characterized by four-circle x-ray diffraction, AFM, STM, resistivity vs. temperature, J_c vs. temperature and magnetic field. Finally, films were patterned and characterized for their nonlinear microwave properties, and compared with results from other deposition techniques by Dan Oates at MIT Lincoln Laboratory.

Accomplishments/New Findings

Growth of YBCO thick films on miscut LSAT substrates

There are good theoretical grounds to expect improvement in nonlinear behavior with thicker films. The thicker film reduces the current density at a given power level so that the nonlinear effects are reduced. Efforts to produce thicker films for improved microwave performance, however, have not been successful because both the film quality degrades and the flux pinning decreases as the film is grown thicker. We have grown

YBCO films with various thickness, 200, 400, 800 and 1200 nm. Figure 1 shows that the nonlinearity degrades as the films are grown thicker due to the degradation of the crystalline quality and flux pinning of YBCO films.

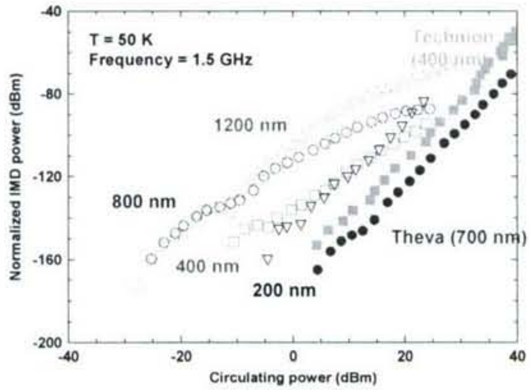

Figure 1 IMD of YBCO films as a function of film thickness.

Growth and IMD of YBCO/CeO$_2$ Multilayers

In order to overcome the degradation of the crystalline quality of YBCO and enhance the flux pinning we have grown epitaxial YBCO/CeO$_2$ multilayers stacks on 2 degree miscut (001) single crystal LSAT substrates by PLD at different substrate temperatures. Recently, it has been reported that multilayer films maintain high J_c values even in the case of thicknesses for which a single-layer film would show significant degradation. Figure 2 show the schematic of the multilayer structure. The multilayer structures have substantially higher J_c than single layer YBCO thin films with the same thickness. The J_c of the single layer YBCO with the same thickness is only 0.94A/cm^2. Furthermore, the multilayer films grown at lower substrate temperature (780 C) has much higher J_c (4.1 MA/cm^2) than multilayer films grown at high substrate temperature (825 C) (see Figure 10).

The results of the first measurements of a YBCO/CeO$_2$ multilayer grown by PLD with *in situ* high pressure RHEED are shown in Figure 2, which compare a single-layer film of 400-nm thickness with a four-layer film with each YBCO layer 160-nm thick interspersed with CeO$_2$ buffer layers 40-nm thick, giving an aggregate thickness of 640 nm of YBCO. *The improvement is dramatic*. YBCO/interlayer multilayers have been expected on theoretical grounds to show improvements in IMD and in power handling. *If verified, these results represent a significant improvement in IMD reduction and power handling increase.*

Thus, the multilayer films may be a method to also provide high-power capabilities to YBCO microwave devices. The outlook, however, is good for two reasons: first, the thicker films reduce the current density, and, second, it is expected that the thinner layers will enhance the pinning and thereby improve losses at high power levels because flux penetration and flux motion are sources of loss.

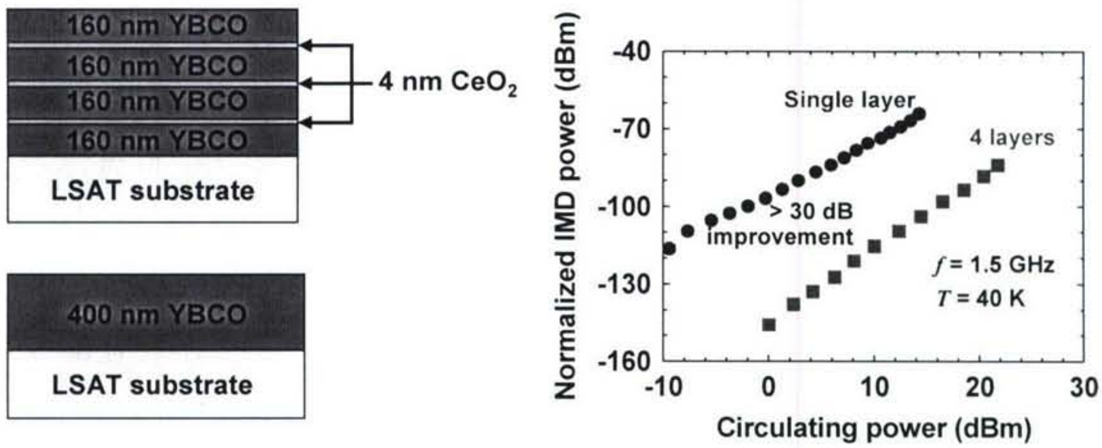

Figure 2 (a) Schematic description of YBCO single layer and YBCO/CeO_2 multilayer on (001) LSAT substrates, (b) Third-order intermodulation distortion at 40 K for the single-layer film and the four-layer YBCO/CeO_2 multilayer film. The frequency is 1.5 GHz. The IMD is lower for the four-layer film over most of the power range by about 30 dB. At high power the single-layer film is saturated and the IMD is no longer a meaningful quantity